SOURCE COUNTS AND BACKGROUND RADIATION

A. Franceschini[1], H. Aussel[2], A. Bressan[3], C.J. Cesarsky[2], L. Danese[4],
G. De Zotti[3], D. Elbaz[2], G.L. Granato[3], P. Mazzei[3], L. Silva[4]

[1]Dipartimento di Astronomia di Padova, I-35122 Padova, Italy
[2]Service d'Astrophysique, CEN, Saclay, France
[3]Osservatorio Astronomico di Padova, I-35122 Padova, Italy
[4]S.I.S.S.A., Trieste, Italy

ABSTRACT

Our present understanding of the extragalactic source counts and background radiation at infrared and sub-mm wavelengths is reviewed. Available count data – coming in particular from a very deep survey by ISO in the near- and mid-IR and from deep IRAS surveys at longer wavelengths – are used to constrain evolutionary models of galaxies and Active Nuclei.

The extragalactic IR background radiation (CIRB), on the other hand, provides crucial information on the integrated past IR emissivity, including sources so faint to be never accessible. Two spectral bands, the near-IR and sub-millimeter – where local foregrounds are at the minimum – are suited to search for the CIRB. These cosmological windows are ideal to detect redshifted photons from the two most prominent broad emission features in galaxy spectra: the stellar photospheric 1 micron peak and the one at 100 micron due to dust re-radiation. The recently claimed detection of an isotropic diffuse component at $\lambda \simeq 100 - 200 \ \mu m$ would support, whenever confirmed, the evidence for strong cosmic evolution from $z = 0$ to $z \sim 2$ of faint gas-rich late-type galaxies, as inferred from direct long-λ counts. Furthermore, an equally intense CIRB flux measured in the wavelength range 200 to 500 μm may be in support of models envisaging a dust-enshrouded phase during formation of spheroidal galaxies (e.g. Franceschini et al., 1994): the background spectrum at such long wavelengths would indicate an high redshift ($z > 2 - 3$) for this active phase of star formation, implying a relevant constraint on structure formation scenarios.

We argue that, given the difficulties for sky surveys in this spectral domain, only sporadic – and probably inconclusive – tests of these ideas will be achieved in the next several years. Only a mission like FIRST, in combination with large mm arrays and optical telescopes, will allow to thoroughly investigate, via photometric and spectroscopic surveys, these IR-bright early phases in the evolution of galaxies and AGNs.

Key words: source counts; evolution; background radiation.

1. INTRODUCTION

Remarkable progresses have been recently made in the exploration of the high-redshift universe at optical and near-IR wavelengths. A combined effort of high spatial resolution (e.g. with the HST), large collecting power (e.g. with the Keck telescope) and suitable selection techniques (e.g. the Lyman "drop-out"), have allowed to discover and characterize galaxian units up to redshifts of the order of 5.

Beyond the K-band spectral limit and up to 20 μm, the ISO mid-IR camera has started to complement the optical data with a sensitive coverage in this previously mostly unexplored domain.

Finally, the three decades in frequency longward of 20 μm up to the radio band will be somehow tackled by various missions and observational campaigns, but are likely to remain a poorly explored field in the foreseeable future. In particular ISO, which is observing here with the long-wavelength camera PHOT, has a limited sensitivity due to the small primary collector and the correspondingly high confusion noise, but similar problems are also likely to limit SIRTF at $\lambda > 50 \ \mu m$. Bolometer arrays on large millimetric telescopes are powerful instruments, but confined to quite small sky coverages because of the small number of detector elements and very long integration times needed to overcome the atmospheric noise even in the 2-3 cleanest spectral windows.

In spite of these and other efforts, exploring the distant universe will keep increasingly difficult at increasing λ for many years to come. It is then worthwhile to review here the possible impact a mission like FIRST would have in this context.

Apart from useful constraints on specific galaxy evolutionary scenarios devised to coherently interpret an exceedingly large dataset, a general lesson we can infer from available data on distant galaxies is that *results in a given waveband may be very hard to reproduce at other wavelengths* and that *properties of galaxy emissivity and evolution are strongly dependent on the selection wavelength.*

So, the assessment of FIRST's capabilities in the cos-

mological context has inevitably to deal with somewhat model-dependent and indirect arguments. Nevertheless, and to anticipate our main conclusions, we argue that ESA's cornerstone mission FIRST will have a profound impact on cosmology and will address problems which can be tackled in no other way.

The paper is organized as follows. The present status of the observations and interpretations of faint galaxy samples in the IR are summarized in Sects. 2 and 3, while the complementary constraints set by observations of the IR background are mentioned in Sect. 4. A tentative scheme of galaxy evolution, discussed in Sect. 5, is used in Sect. 6 to predict and discuss the impact of FIRST in the exploration of the distant universe, and to compare it with other future far-infrared and sub-millimetric facilities.

2. GALAXY COUNTS IN THE IR: CURRENT OBSERVATIONAL STATUS

The number-flux relationship of cosmological sources – combined with information on the local luminosity functions and the spectral K- and evolutionary corrections – is a classical test of evolution of the source emissivity with cosmic time.
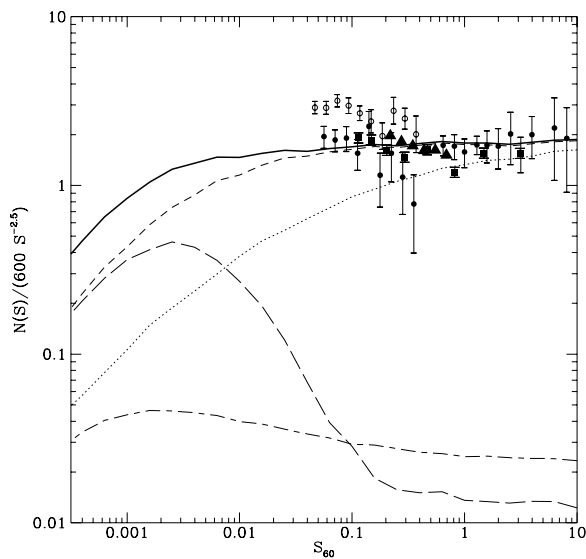

Figure 1. Differential galaxy counts of galaxies at 60 μm normalized to the euclidean law $600S^{-2.5}\ sr^{-1}/Jy-1$. The sources of the data are mentioned in Sect. 2.1. The dotted line correspond to the predicted no-evolution case (Sect. 3.1). The short-dashed line is the predicted counts for gas-rich evolving galaxies (including spirals, starbursts, irregulars. Long-dashes correspond to dust-emission from early-types (E/S0) during an early evolution phase. Long-short dash are AGNs. More details on the models are provided in Sect. 3.3.

With the aim of constraining galaxy evolution schemes to be used in the following Sects., we briefly summarize here the presently available scanty information on source counts in the infrared.

2.1. Counts based on the IRAS survey

The all-sky survey by IRAS has revealed a numerous local population of luminous dust-rich star-forming galaxies at $z < 0.1$. But, in addition, in a repeatedly scanned fraction of the sky IRAS has reached flux limits faint enough to start detecting galaxies at cosmological distances.

Faint number counts of galaxies at 60 μm (where Galactic cirrus contamination is at the minimum and survey sensitivity at the maximum) have been discussed by Hacking & Houck (1987), Gregorich et al. (1995), Bertin, Dennefeld, Moshir (1997), while the bright-flux normalization to local source populations was based on analyses of the PSC by Rowan-Robinson et al. (1991). A collection of 60 μm differential counts is reported in Figure 1. As shown there, the counts at faint fluxes appear in excess of no-evolution extrapolations from the bright flux limits.

Extensive efforts of optical identifications and spectroscopic follow-up by Saunders et al. (1990, 1997), Lonsdale et al. (1990), Oliver et al. (1995) support conclusions in favour of evolution (even a strong one) by Franceschini et al. (1988), Lonsdale et al., Oliver et al.

However, as the few most distant galaxies in the faintest samples are found at $z \simeq 0.2 - 0.3$, any conclusions based on IRAS are to be taken as tentative only, large-scale inhomogeneities possibly affecting such shallow samples.

2.2. Near- and mid-IR counts by ISO-CAM

The Infrared Space Observatory has recently allowed some very significant, though preliminary, steps forward. The occasion was a long integration with the well-performing mid-IR camera ISOCAM in two filters (LW2=5-8.5 μm, LW3=12-18 μm) on the very extensively studied Hubble Deep Field (Rowan-Robinson et al., 1997). Redundancy in the number of elementary integrations per sky pixel have allowed to reach the faintest limiting fluxes ever at these λ, three decades fainter than IRAS at 12 μm.

Source counts at the effective wavelengths λ=6.7 and 15 μm are discussed by Oliver et al. (1997) and results appear in Figures 2 and 3. Number of detections and sky coverage are 27 sources/5 sq.arcmin and 22 sources/15 sq.arcmin, respectively. As can be seen, the source confusion limit for the ISO 60-cm primary collector is almost reached at 15 μm. A refined analysis of these data, based on a multi-scale wavelet transform (Stark et al., 1997), is reported by Aussel et al. (1997).

Various other similarly deep CAM surveys both in GT and OT are being performed over more significant sky areas (see C. Cesarsky, these Proceedings), while a shallow survey over 20 square degrees is being performed by the European Large Area ISO Survey (ELAIS, M. Rowan-Robinson, these Proceedings) over 20 square degrees.

A potentially useful match with these data comes from the extensive ground-based surveys in the K
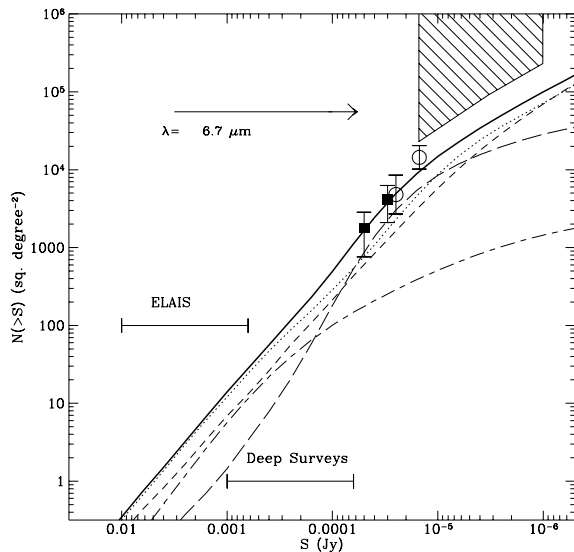
Figure 2. *Integral galaxy counts of galaxies at 6.7 μm based on the CAM-LW2 survey in the HDF (see Oliver et al. for more details). Meaning of the lines as in Fig. 1. The horizontal line marks the areal density corresponding to a confusion-limited survey. See Oliver et al. for more details.*
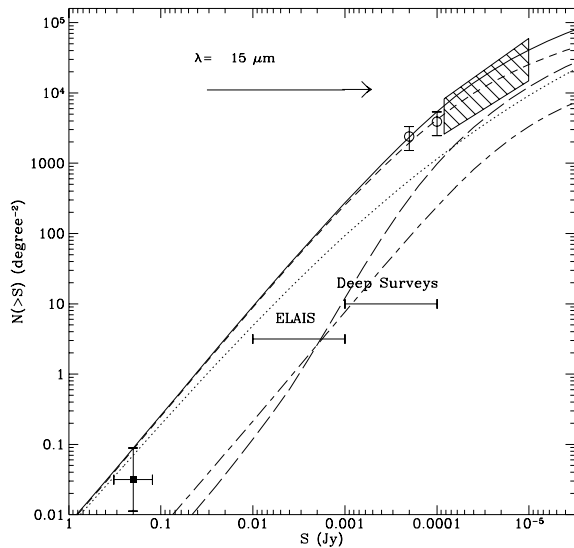

Figure 3. *Integral galaxy counts at 15 μm based on the CAM-LW3 survey in the HDF. The shaded region corresponds to a boundary on the counts coming from an analysis of the background fluctuations in the ISO LW3 map.*

band. Figure 4 summarizes some results on galaxy counts.

2.3. Far-IR counts by ISO-PHOT

While the ISO long-wavelength camera C100 is still under test, the C200 camera covering the 120-240 μm range is already successfully and rutinely performing. A deep survey has been performed by Kawara et al. (these Proceedings) with PHT C200 at $\lambda = 175$ μm over 22'x22' in the Lockman Hole (at the absolute minimum of the Galactic 100 μm emission).

Probable extragalactic sources, unrelated to "cirrus" emission, have been found, with preliminarily calibrated fluxes close to or below 100 mJy (see in Figure 5 the corresponding counts). Optical counterparts are either faint or absent on POSS, indicative of remote galaxies. Indeed we expect that the positive K-correction at such long-λ operates to favour selection of fairly high-z with respect to low-z galaxies.

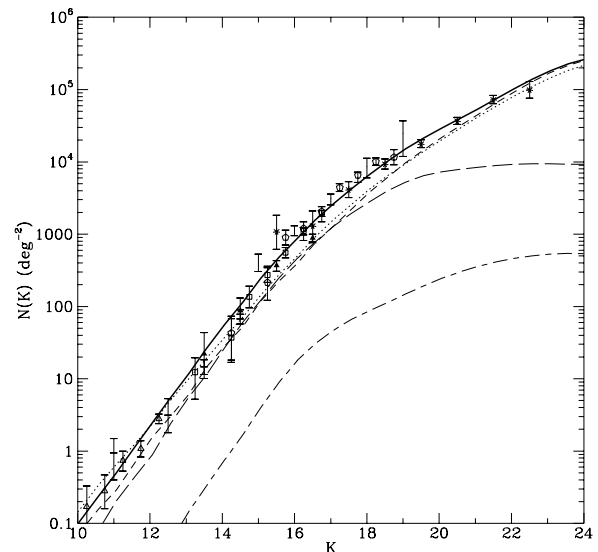Similar ISO-PHOT surveys over larger sky areas are being performed by Kawara et al. and Puget et al.

Figure 4. *Differential galaxy counts in the K band ($\lambda = 2.2\mu m$). Data collected by Gardner et al. (1995). Meaning of the lines as in the previous figures.*

3. INTERPRETATIONS OF THE IR COUNTS

As previously mentioned, thanks to ISO we are presently in the course of a real quantum jump in our knowledge of distant IR sources. Only a tiny fraction of ISO survey data are presently analyzed, much more information will be available in one year from now. Nevertheless, it is of interest to try to infer from the present data constraints on galaxy evolution to be compared with the optical data and suitable to discuss the possible impact of future missions.

3.1. The λ-dependent local luminosity function

The local luminosity function (LLF) is a fundamental constraint on the evolutionary history of galaxy

emissivity. In the IR-mm, its knowledge mostly relies on the IRAS all-sky surveys and on wide-area surveys in the K-band. We used galaxy LLF by Saunders et al. (1990) at 60 μm, by Rush et al. (1993) at 12 μm and a recent evaluation by Gardner et al. (1997) at 2.2 μm. Within the envelopes provided by these global LLFs, further subdivision into different morphological classes is made following Franceschini et al. (1988b).

The λ-dependent LLF has been extrapolated to $\lambda > 100$ μm by Franceschini, Andreani & Danese (1997) using 1.3 mm observations of a complete sample of 30 bright IRAS galaxies selected at 60 μm, and convolving the IRAS LLF with a IR-mm bivariate luminosity distribution. This is very critical for the interpretation of source counts and background data at long wavelengths. We note, however, that this procedure could potentially miss some faint dust-rich and cold galaxies. Mm-selected galaxy samples, impossible to get before the PLANCK Surveyor and the FIRST mission, would be needed to prove this.
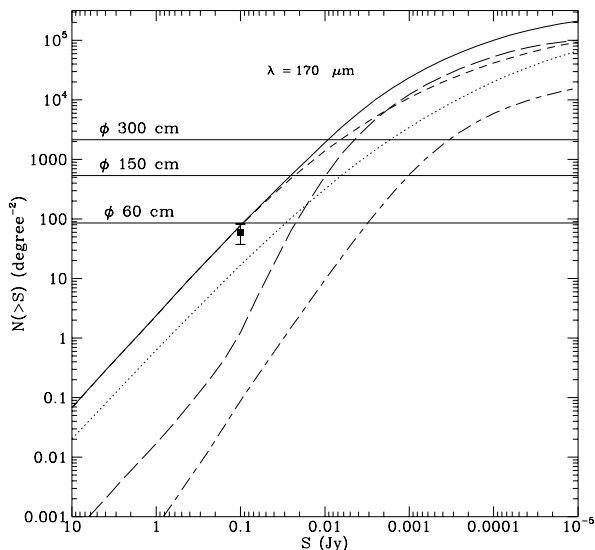

Figure 5. Galaxy integral counts at $\lambda = 170$ μm. The data-point is based on Kawara et al. (see Sect. 2.3). Meaning of various lines as in previous figs. The orizontal lines mark the onset of confusion as a function of the primary collector's diameter. Note the importance of the latter parameter for space missions at these wavelengths. According to this, a 3.5m FIRST is not expected to be confusion limited above a flux $S_{170} \sim 5 mJy$.

Substantial contributions by ISO are soon expected. In particular at $\lambda = 170$ μm the ISOPHOT Far-IR Serendipity Survey (Bogun et al. 1996), is covering in the ISO slew mode about 15% of the whole sky and detecting some ~ 3000 galaxies to $S_{170} > 1$ Jy. ELAIS (see above) is surveying at $\lambda = 95$ and 15 μm twenty square degrees to ~ 20 mJy and 1 mJy, respectively, while additional smaller areas are being mapped by the Guaranteed Time Shallow Survey (C. Cesarsky, these Proceedings). At least hundreds of local galaxies are expected at each λ.

Knowledge of the local IR volume emissivity of galaxies allows a zero-th order evaluation of possible evolu-

tionary effects traced by the observed number counts. The differential counts per sr at a given flux S are given by:

$$\frac{dN}{dS} = \int_{z_l}^{z_h} dz \, \frac{dV}{dz} \, \frac{d \log L(S,z)}{dS} \, \rho[L(S,z),z] \quad (1)$$

where $\rho[L(S,z),z]$ is the epoch-dependent luminosity function and dV/dz is the differential volume element (per unit solid angle). Flux S and rest-frame luminosity L are related by

$$S_{\Delta\nu} = \frac{L_{\Delta\nu} K(L,z)}{4\pi d_L^2}, \quad (2)$$

where d_L is the luminosity distance and $K(L,z) = (1+z)\frac{L[\nu(1+z)]}{L(\nu)}$ the K-correction. A no-evolution evaluation is made assuming $\rho[L(S,z),z] = \rho[L(0),z=0]$ and $z_h = 1$.

As shown in Figs. 1 to 5 (dotted lines), comparison with the available counts of predictions based on no-evolution models already shows a remarkable dichotomy. While very moderate evolution is indicated in LW2 (5-8.5μm) and in K-band, much stronger evolution effects with redshift are required to explain the observed ISOCAM counts in LW3 (12-18 μm), the IRAS 60 μm and the ISO-PHOT 170 μm counts.

3.2. IR galaxy spectra and optical morphology

Essential information to interpret the observed number counts may be inferred from optical identifications of ISO-HDF and of IRAS deep samples.

A useful guideline for our discussion is to split the IR domain in two parts, according to the expected dominant astrophysical contributor:
a) the near-IR domain (1-8.5 μm), dominated by starlight emission, and including K-band and ISO-CAM LW2;
b) the far-IR part (10-1000 μm), dominated by dust reprocessing (by warm dust, PAH, small grains, and cooler dust at $\lambda \sim 100$ μm), and including ISO-CAM LW3, ISO-PHOT and IRAS 60 μm.

Galaxy samples selected in the near-IR show composite morphologies, including early-types (E/S0), dominated by photospheric emission from old stellar populations, and late-type, gas-rich systems (Sa through Irregulars). Sources in the ISO-HDF sample, in particular, have been identified by Mann et al. (1997). The optical through IR broad-band spectrum of a $z = 1$ elliptical is shown in Figure 6. The spectrum is fitted by an old (t=4 Gyr) and already massive ($M = 4\,10^{11}\,M_\odot$) stellar population at that redshift. As for the morphology, in the WFC high-resolution image the galaxy looks as a plain, very regular system, in no way dissimilar to local massive ellipticals. This sets an interesting lower limit to the age of the universe and constrains the formation of very massive field galaxies.

More general conclusions are drawn with reference to the source list by Aussel et al. (1997). Sources identified with E/S0's are typically found at $z \sim 1$, because of the combined effect of K-correction plus
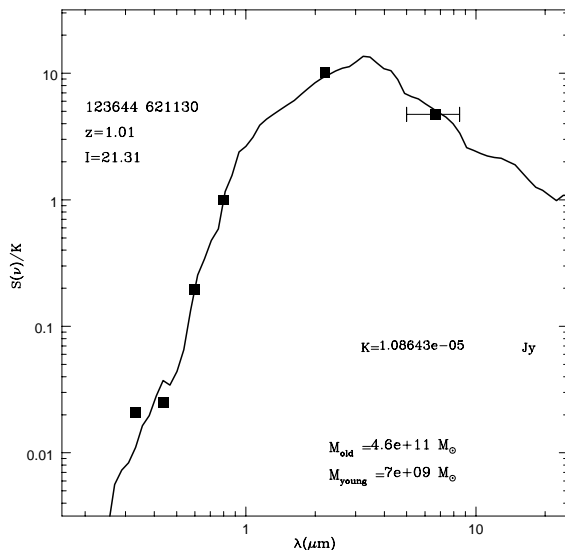
Figure 6. Broad-band optical-IR spectrum of a z=1 elliptical galaxy in the ISO-HDF sample. See Mann et al. (1997) for the optical and LW2 fluxes. The K-band flux comes from the KPNO IRIM image. The model assumes a 4 Gyr old stellar population with a mass of $4\ 10^{11}\ M_\odot$ plus the contribution of a younger (1 Gyr) component including 2% of the barionic mass.

some moderate [passive] evolution. Objects identified as Sp/Ir's are found at lower redshifts ($z = 0$ to 0.5).

On the contrary, the small far-IR sample selected by CAM-LW3 and identified in the HDF includes exclusively gas-rich systems (Spirals/Irregulars and Starbursts) at substantial redshifts (z=0 to ~ 1). Studies of faint 60 μm galaxies and hyper-luminus IRAS galaxies also emphasize normal spirals at moderate luminosities/redshifts and of starbursts at higher L,z values.

3.3. IR galaxy counts: interpretation

Moderate evolution is indicated by galaxy counts in the near-IR domain ($1 < \lambda < 8.5\ \mu m$). This is fully consistent with purely passive evolution at redshifts less than a few to several for the E/S0 population: the brighting is of typically less than 1 mag by z=1 to 1.5. Similar conclusions are derived for galaxies in high-z clusters, but it would be essential to test them in the field population to understand if there are any significant differences.

The other component, the gas-rich systems, are also bound to evolve very slowly at these wavelengths, again consistent with the evidence that the flux is mostly contributed by old stellar populations whose mass and luminosity slowly evolve with cosmic time. These recipes (i.e. pure luminosity evolution, z_{form}=2.5 and z_{form}=7 for late- and early-type galaxies, as discussed in Franceschini et al. 1991) have been used to compute the contributions of E/S0's and Sp/Ir's in Fig. 2. Their sum fits very well the 6.7 μm galaxy counts and also the K-band counts in Fig. 4.

On the other hand, the strong evolution required by the far-IR galaxy counts clearly concerns a different emission component, i.e. dust illuminated by massive stars. The observed evolution is perhaps due to an increased rate of interactions (and merging?) in these gas-rich systems at redshifts $\simeq 1$. Similar evolutionary effects are observed at short optical wavelengths (the Faint Blue Galaxies, see e.g. Ellis 1997), in the radio and perhaps in the X-ray band too. We do not have yet a self-consistent physical description of this evolution of gas-rich late-type systems, we just modelled it with a kynematical increase of the luminosity as $L(z) = L(0)\ e^{2\tau(z)}$ in an open universe ($q_0 = 0.15$) (see the short-dashed lines in Figs. 1, 3 and 5).

Is there a conflict between this evidence of strong evolution in the FIR for gas-rich systems and their lack of evolution in the NIR? This may not be the case if we consider that NIR observations sample the integrated emission of aged stellar populations, and are then very weakly sensitive to evolution, while the FIR (and also the optical-UV and radio) sample transient enhancements of massive-star formation due to interactions, more frequent in the past. These short-lived ($\Delta t \sim$ a few $10^7\ yr$) starbursts may not add much to the mass of long-lived red stellar populations observed in the NIR, where they could even be hardly observable.

We have also assumed in Figs. 1 to 5 that the early-type E/S0 systems evolve according to Franceschini et al. (1994), who suggested that a bright phase of star formation and metal production at z$\sim$ 2 to 5 is obscured by dust present in the ISM and quickly produced by the early stellar generations. As it appears in the figures, given their high redshift and faintness, it is unlikely that these objects will be detected by ISO.

Finally, the contribution of AGNs in the FIR has been computed assuming the existence of a numerous population of self-absorbed objects advocated to explain the X-ray background (see Granato et al. 1997 for more details).

4. CONSTRAINTS FROM THE IR BACKGROUND ON THE STAR FORMATION HISTORY

The difficulty to access faint distant sources in the IR, and the availability of two fairly clean spectral windows in the near-IR and sub-mm, make the cosmic IR background an essential too to investigate the distant universe. Implementation of high-sensitivity detectors on space platforms (COBE) have allowed to approach detection of the CIRB in both channels. Data and model predictions on the CIRB are summarized in Figure 7. The lower dotted curve corresponds to the minimal expected contribution from non-evolving galaxies, an estimate relying uniquely on the λ-dependent LLF (see Sect. 3.1). We may already see some confirmations of our findings in the previous Sects.: a narrow margin available for evolution in the NIR, and wide room allowed by current limits in the FIR/sub-mm.

4.1. The near-IR background

For $1 \mu m < \lambda < 8.5 \mu m$ the galaxy contribution to the CIRB (thick line in Fig. 7) is estimated assuming the best-fit model of Figs. 2 and 4. The constraints set by very deep counts of galaxies in the K band and recently by ISO at $6.7 \mu m$ (Oliver et al. 1997) make this estimate quite a robust one.
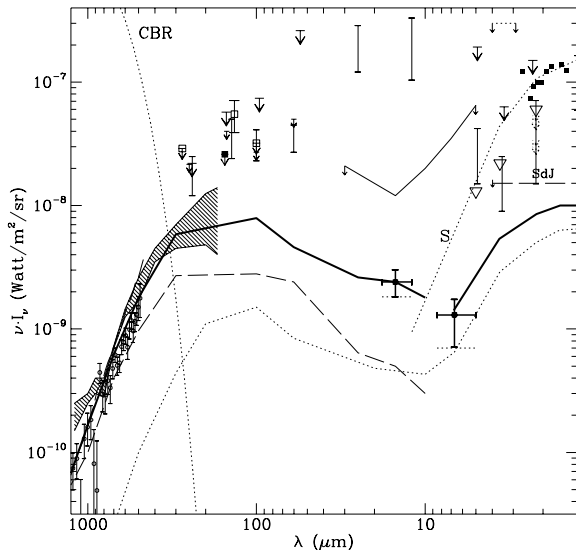

Figure 7. The extragalactic IR background, data versus model predictions. Data at the long-λ part are from Puget et al. (1996) and Fixsen et al. (1997). Vertical bars are limits to the CIRB by Hauser (1996). Open triangles are upper limits by Kashlinsky et al. (1996). The curve marked SdJ is from Stecker & De Jager (1996) and the limits at 5 to 30 μm are from Dwek & Slavin (1994). Curve S is the integrated starlight at the galactic pole. The lower dotted line is the predicted flux for no evolution. The dotted line is the partial contribution due to high-z dusty spheroids. The two data-points at 6.7 and 15 μm come from an evaluation of the distant galaxy background based on the best-fit model discussed in Sect. 3.3 and fitting available counts at these wavelengths. The corresponding lower dotted lines show the background intensity already resolved by ISO-CAM into discrete sources. See Sect. 4 for more details.

Observational limits, namely the Hauser (1996) and Stecker and de Jager (1996) estimates and the one by Kashlinsky et al. (1996) based on a CIRB auto-correlation analysis, are already quite close to such a predicted background. Altogether, the **current information is consistent with the NIR background mostly originating from ordinary stellar populations in galaxies and very seriously limits any residual contributing signals from high-z processes** (e.g. pre-galactic stars, emissions by primeval collapsed objects, decaying particles).

4.2. The FIR/SUB-MM background

Given a most favourable combination of the foregrounds, we could have had perhaps here **the first**

ever detection of the integrated emission of distant galaxies** in the form of an isotropic signal discovered by Puget et al. (1996), whose spectrum is reported in Fig.7 at $200 < \lambda < 500 \mu m$. A discussion is now underway to ascertain that this signal is not due to, e.g., a cold dust halo in our galaxy or in the solar neighbourhood. Without entering the controversy, let us illustrate the possible impact of such a detection on the structure formation issue.

Dust emission spectra for a wide range of galaxy populations are all rather similar, due to the weak dependence of dust equilibrium temperature on the radiation field intensity ($T_d \propto I_\nu^{1/5}$). Then a knowledge of the CIRB spectral intensity at $\lambda \geq 100 \mu m$ translates rather directly into a constraint on the effective redshift z_{eff} of sources making it. Available data on the CIRB sub-mm spectrum constrain z_{eff} to be (Burigana et al. 1997):

$$1 + z_{eff} \simeq (3 - 5) \left(\frac{T_d}{50 \ K} \right) \qquad (3)$$

Similarly, the CIRB's observed intensity demands an energetics which is a function of the redshift z_{eff} when the SF event occurred, of the temperature T_d of the re-processing dust, the fraction F_{FIRB} of the light re-processed into the IR, the efficiency ϵ of energy production by stellar processes. We can express this energy in terms of the fraction f of the total barions, as inferred from primordial nucleosynthesis, which have been processed by this high-z SF event to produce a solar metallicity:

$$f \simeq 0.1 \frac{0.05}{\Omega_b} \frac{Z_\odot}{Z} \frac{1}{F_{FIRB}} \frac{0.007}{\epsilon} \left(\frac{T_d}{50 \ K} \right)^{2.5} \left(\frac{4}{1 + z_{eff}} \right)^{1.5},$$
$$(4)$$

(where it is assumed $\Delta Y = 2.5Z$ and $Z_\odot = 0.02$). This fraction is consistent with the barion mass and metallicity of local early-type and cluster plasmas.

As shown in Fig.7 (thick line), the model fitting FIR and sub-mm counts, assumed $T_d \simeq 50 \ K$ for the intense star-burst phase at $z_{eff} \simeq 4$, predicts a far-IR/sub-mm background in close agreement with the Puget et al. measurement. This is perhaps not as easy for typical models of hierarchical clustering based on the $q_0 = 0.5$ paradigm, which predict the main starburst phase occurring too late in cosmic time to reproduce the CIRB spectrum at long-wavelengths: the general tendency for these models may be to synthesize excess flux at $\lambda \sim 100 - 200 \mu m$, and much too little longwards.

This stresses the importance of confirming, or disproving, the FIR/sub-mm background, to gain a fairly direct test of – otherwise currently undetectable – SF processes.

5. A TENTATIVE SCHEME FOR GALAXY EVOLUTION

IR observations (and to some extent optical and radio observations too) provide consistent indications in favour of a bimodal pattern for galaxy evolution:
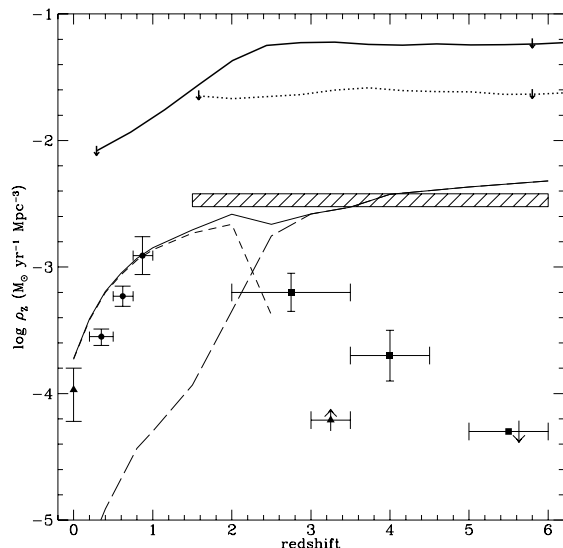
Figure 8. The history of the cosmic metal production rate. Data-points are evaluations based on optical galaxy surveys: the CFRS survey at z < 1 and on high-z galaxies selected with the "Lyman drop-out" technique. The shaded region is an estimate by Mushotzky & Loewenstein (1997) using as a constraint the metals observed in galaxy clusters. Upper lines are limits based on a conservative analysis of COBE residuals by Burigana et al. (1997). Long and short dashes correspond to the two evolutionary branches of high-z dusty spheroids and low-z gas-rich systems.

(a) the so-called early-type E/S0 systems, already quite old at z=1-2, evolve passively from that epoch to the present time; their formation should be confined to $z > 2$;
(b) late-type gas-rich disk-dominated systems make stars fairly actively at z=1-2 and below, i.e. over most of the Hubble time.

This scheme is illustrated in Figure 8, where a lot of information on the history of star formation and metal production is summarized. The two galaxy populations imply two different branches in this evolutionary history: the branch at $z < 2$ corresponds to the phase of star and metal production in gas-rich systems, while the wide plateaux at z=2 to 6 marks the active, dust enshrouded phase of spheroid formation. Data points are estimates of the metal production rate based on optical observations: it is clear that, according to these data, the high-redshift branch should be mostly unobservable in the optical, consistent with the view that most of the light was dust-reprocessed into the IR/sub-mm.

In addition to the above discussed indications for a high-redshift phase of excess SF based on the old field galaxies observed at high-z (Sects. 3.2 and 3.3) and on the requirements set by the Cosmic IR/sub-mm Background (Sect. 4.2), independent evidences come from:

i) the early-type galaxy populations in galaxy clusters, passively evolving to $z = 1.2$ (e.g. Dickinson 1997), the large amounts of metals and the lack

of evolution in the temperature and density of the Intra-Cluster Medium up to $z = 0.7$ (Mushotzky & Loewenstein, 1997); **note in particular the impressive agreement in Fig. 8 between the estimated rate of production of metals in the ICM and our curve needed to reproduce the sub-mm background;**

ii) the copious amounts of dust observed in high- and very high-z QSO's (see Andreani et al. [these Proceedings]);

iii) the amounts of metals in the environments of high-z QSO's (as shown by the associated absorbers, see Franceschini & Gratton, 1997).

A major episode of star formation at $z > 2$ has obvious significant implications for structure formation scenarios. Combined with clues of the existence of massive clusters already in place at $z >> 1$ from SZ observations (Richards et al. 1997), with direct evaluations of Ω based on measurements of the global M/L of galaxy clusters and its redshift evolution (Carlberg et al. 1997), and with the observed barion fractions in clusters, then all this may require modification of the gravitational instability picture based on the conventional Ω=1-CDM paradigm.

6. OPEN PROBLEMS, AND WHO COULD CONTRIBUTE TO SOLVE THEM

We believe that disprove or substantiation of the tentative scheme of galaxy formation and evolution outlined in Sect. 5, versus other alternative interpretations, will be one of the crucial motivations of observational cosmology in the next several years. The present Section is devoted to a short discussion of three related open questions, with the aim of clarifying the opportunities and limitations of planned facilities.

6.1. Properties of the evolving population of gas-rich late-types and irregulars at $0 < z < 2$

Essentially in any accessible wavebands (apart the near-IR), populations of active galaxies have been discovered with perhaps similar properties to those of gas-rich systems found in the IR:

a) in the optical-UV the Faint Blu Objects dominating the short-wavelength optical counts at faint magnitudes (see e.g. Ellis 1997);

b) in the radio centimetric, the milli-Jy to micro-Jy radio galaxy population responsible for the upturn of the radio counts;

c) the narrow emission-line galaxies associated with faint X-ray ROSAT sources at $S \leq 10^{-14}\ erg/cm^2/s$ (McHardy et al., 1997).

The relationships among these various populations of active and starbursting galaxies are at the moment quite unclear. What is indicated by existing data is that there is no template spectrum for the whole population. The Spectral Energy Distribution (SED's)
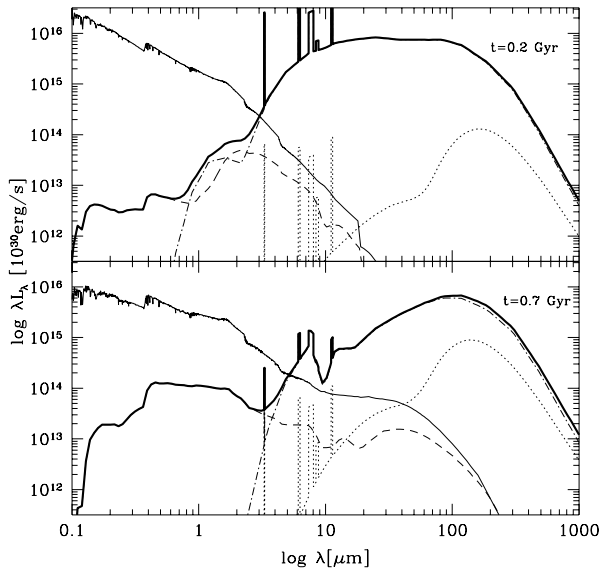
Figure 9. Predicted rest-frame spectra at two ages (0.2 and 0.7 Gyr) of a star-forming galaxy with $M = 5\,10^{11}\ M_\odot$, a decay time for the SF of $\tau = 0.5$ Gyr, forming stars at rates of 700 and 400 $M_\odot/yr$ at the two respective ages, and producing a galactic wind at an age of 0.75 Gyr. The thin continuous line is the optical unabsorbed spectrum, the dashed line the absorbed one, the dot-dashed the emission by molecular clouds and the dotted line is the cold "cirrus" emission. The fractions of residual gas are 0.7 and 0.4, while the dust/gas is 0.002 and 0.009 (proportional to the metallicity), respectively. Star-forming regions are modelled as molecular clouds, assumed to include 30% of all residual gas at any moment (see and Granato et al., these Proceedings, for more details).

may dramatically depend on the galaxy's morphological type, selection wavelength, age of the object and cosmic epoch. Points to be understood would be, in particular:

a) does the IR-selected evolving population of starburts coincide with the moderate-to-low mass systems dominating the blue optical counts?, or

b) is it a somewhat unrelated population of more massive objects, strongly interacting and probably merging, like the hyperluminus IR galaxies?

c) what is the origin of the strong observed evolution with redshift up to at least $z = 1$?

d) what is the amount of barions locked into stars in this relatively late phase? Note that the mass in stars might not be strictly related to the amount of metals appearing in Fig. 8, if e.g. the IMF varies.

FIRST will characterize the dust emission spectrum in a critical range (~ 80 to $600\ \mu m$) where peak emission is expected to be observable. Figure 9 reports the synthetic spectrum of a massive starburst galaxy observed after 0.2 and 0.7 Gyr from the onset of the SF. FIRST's spectral coverage will then sample the redshifted photons bringing the bulk of the energy during a sizeable fraction of galaxy's lifetime. Given

the moderate redshifts this phenomenon is occurring at, important contributions will also come from post-ISO moderate-size IR missions, like SIRTF, sampling the critical window, from a few μm to a few tens of μm, where hot dust in the star-forming regions is emitting. FIRST and planned IR space facilities are very nicely complementary on this respect.
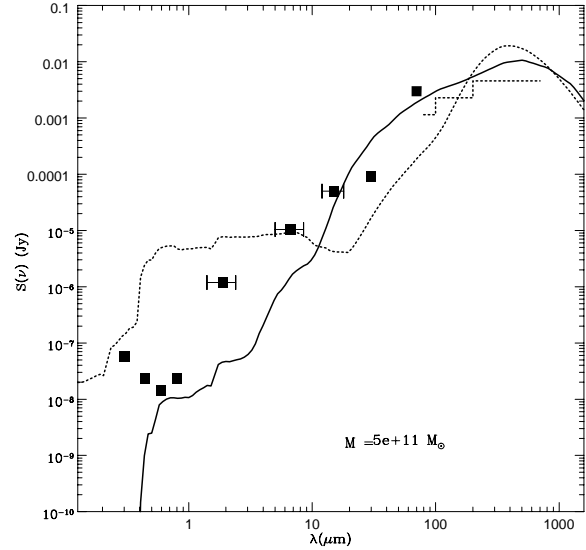

Figure 10. Predicted spectrum in the observable plot (flux versus observed wavelength) of a massive primeval star-forming galaxy with z=3.5 (see text). The rest-frame spectra are those reported in Fig. 9. These predictions are compared with sensitivities for long integrations (3 hours) of, from left to right, HST Hubble Deep Field in U, B, V, I, K=22, ISO-CAM LW2 and LW3 and SIRTF at 30 and 70 μm. The dotted step-like line is the predicted sensitivity of FIRST. Note that the SIRTF long-wavelength sensitivity is limited by confusion noise.

6.2.   Formation and early-evolution of AGNs and QSOs

We have seen that the evolution rates of IR-selected starburst populations are comparable to those of optical and X-ray quasars ($L[z] \propto [1 + z]^{2-3}$). Basic questions are:

i) How the starburst is related to the AGN phenomenon? Are evolving luminous and hyperluminous IR galaxies primarily energized by dusty AGNs?

ii) How super-massive Black Holes (of $M \sim 10^8 - 10^9\ M_\odot$) are formed in quasar nuclei at high-z ? It is common wisdom that this event occurr during early formation of spheroids, probably in a dusty medium, while the classical optical quasar phase would be a late one in the process of QSO formation.

iii) A question more related to local AGN phenomenon, and in particular to the unified model of AGN activity: how many type-II AGN do exist, and how do they evolve?

Answers are likely to come from IR studies. In particular, if (iii) will be addressed also by other missions, points (i) and (ii) will probably require FIRST, because of the redshift effect.

6.3. Evolutionary history of galaxies at $z > 2$

Finally, we consider the class of early-type E/S0 galaxies mentioned in the evolutionary scheme of Sect. 5. The passively evolving, old stellar populations observed at 1 to 8.5 μm by ISO and by K-band ground-based surveys, in both field and cluster galaxies, require that the bulk of the Star Formation making them should have occurred at $z > 2$. This star-formation history has been modelled in Fig. 8 as a wide plateaux, declining at $z < 2$.

Also, if we take the metal abundance measured in X-rays in the Intra-Cluster Medium (assuming it sinthetized by cluster galaxies) as representative of the whole E/S0 population, then the implication might be that the high-redshift SF phase should have involved a massive-star and metal production in excess of the lower-redshift SF branch in Fig. 8.

If all this occurred in a dusty medium (as suggested by lack of detection in the optical, and, on the positive side, by the observed long-wavelength excess in the CIRB), IR surveys are needed to detect it. In this case the redshift should be quite high, and the peak emission would be expected to fall at $\lambda > 100 \mu m$, hence best (or even only) observable by FIRST among the planned IR space missions.

Figure 10 matches the sensitivity for long integrations of various facilities with model spectra of a major starburst at $z = 3.5$, corresponding to the early phase of top Fig. 9. The two curves differ only for the fraction of gas in the molecular phase, which is 30% for the continuous line and 0% for the dotted line. While the optical to far-IR spectrum is much dependent on the age of the object, plus a number of details such as the average dust optical depth, the physical parameters of the star-forming regions, how distant is the dust from the illuminating sources, and so on, the sub-millimeter spectrum is much less affected by these uncertain quantities and implies a robust test for the existence of an early dust-enshrouded phase.

Altogether, FIRST promises some fundamental progresses in our knowledge of the high-z universe. From $\lambda = 80$ to several hundreds μm it appears as a unique instrument for astronomical exploration, even if compared with the most ambitious projects now under scrutiny. In particular, performances of FIRST and of the New-Generation Space Telescope look very much complementary and synergic. FIRST's wavelength range is perhaps where peak emission from forming structures is to be expected.

REFERENCES

Aussel, H., Cesarsky, C.J., Elbaz, D., Stark, J.L. 1997, to appear in "Extragalactic IR Astronomy", Moriond 1997

Bertin, E., Dennefeld, M., Moshir, M. 1997, preprint astro-ph 9610218

Burigana, C., Danese, L., De Zotti, G., Franceschini, A., Mazzei, P. 1997, MNRAS in press

Carlberg, R.G, et al. 1997, preprint astro-ph9704060

Dickinson, M. 1997, preprint astro-ph 9703035

Dwek, E., Slavin, J. 1994, ApJ, 436, 696

Ellis, R. 1997, ARAA in press, preprint astro-ph 9704019

Fixsen D.J., Cheng E.S., Gales J.M., Mather J.C., Shafer R.A., Wright E.L. 1996, ApJ, 473, 576

Franceschini A., Gratton, R. 1997, MNRAS, 286, 235

Franceschini A., Danese L., De Zotti G., Xu, C. 1988, MNRAS, 233, 175.

Franceschini A., Danese L., De Zotti G., Toffolatti L., 1988b, MNRAS, 233, 157.

Franceschini A., Mazzei P., Toffolatti L., Danese L., De Zotti G., 1991, AASuppl. 89, 285.

Franceschini, A., Mazzei, P., De Zotti, G., Danese, L. 1994, ApJ, 427, 140.

Franceschini, A., Andreani, P., Danese, L. 1997, MNRAS, in press

Gardner, J., et al. 1995, ApJ, 415, L9

Gardner, J., Sharples, R., Frenk, C., Carrasco, B. 1997, GSFC preprint 97-4

Granato, G., Danese, L., Franceschini, A. 1997, ApJ, in press

Hacking, P., Houck, J. 1987, ApJ Suppl., 63, 311

Hauser M. 1996, in *Unveiling the Cosmic IR Background*, E. Dwek Ed., AIP Conference Proc. 348, Woodbury, New York, 11

Kashlinsky, A., Mather, J.C., Odenwald, S., Hauser, M.G. 1996, ApJ, 470, 681

Lonsdale, C., Hacking, P., Conrow, T., Rowan-Robinson, M. 1990, ApJ, 358, L60.

Mann, R.G., Oliver, S., Serjeant, S., *et al.* 1997, MNRAS, in press

McHardy, I.M.L., et al 1997, MNRAS, submitted, preprint astro-ph 9703163

Mushotzky, R., Loewenstein, 1997, ApJL in press, preprint astro-ph 9702149

Oliver, S., *et al.*, 1995, in 'Wide-Field Spectroscopy and the Distant Universe', eds. S.J.Maddox and A.Arogon-Salamanca (World Scientific) p.274

Oliver, S., Goldschmidt, P., Franceschini, A., et al. 1997, MNRAS, submitted

Puget J.-L., Abergel A., Bernard J.-P., Boulanger F., Burton W.B., Désert F.-X., Hartmann D., 1996, AA, 308, 5

Richards, E., Fomalont, E., Kellermann, K., Partridge, B., Windhorst, R. 1997, ApJ Suppl., 113, 1475

Rowan-Robinson, M., Mann, R., Oliver, S., et al. 1997, MNRAS, submitted

Rowan-Robinson, M., et al. 1991, MNRAS, 253, 485.

Rush, B., Malkan, M., Spinoglio, L. 1993, ApJS, 89,1

Saunders, W., Rowan-Robinson, M., Lawrence, A., Efstathiou, G., Kaiser, N., Frenk, C.S., 1990, MNRAS 242, 318

Stark, J.L., Aussel, H., Cesarsky, C.J., Elbaz, D. 1997, to appear in "Extragalactic IR Astronomy", Moriond 1997

Stecker, F., De Jager, O. 1996, Space Science Reviews, 75, 401